SENATE HIGHWAYS AND TRANSPORTATION
EXHIBIT NO. 2
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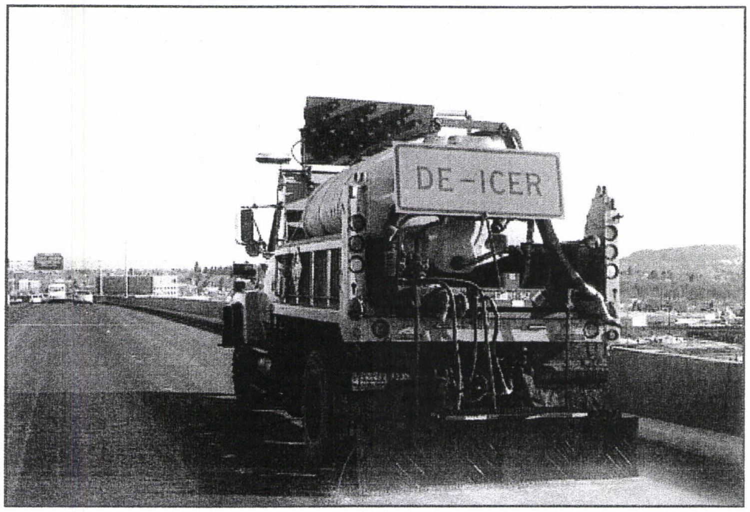

Source Water Protection Practices Bulletin

Managing Highway Deicing to Prevent Contamination of Drinking Water

The mission of EPA is to protect human health and to safeguard the natural environment -- air, water and land -- upon which life depends.

USEPA East (EPA East) [Old ICC Building]
1201 Constitution Avenue N.W.
Washington, DC 20004

EPA United States Environmental Protection Agency

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IMAGE CREDITS

1 - Flickr Creative Commons: Attribution only search. Big Red Snow Plow, uploaded by "ww3billard" on February 9, 2007. http://www.flickr.com/photos/mister_flash/385166864/

2 - Clip Art.

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4 - Flickr Creative Commons: Attribution only search. De-icing at Syracuse, uploaded by "PhillipC" on February 25,2005. http://www.flickr.com/photos/flissphil/5400609/

5 - Flickr Creative Commons: Attribution only search. The Chemistry of Inversion, uploaded by "[F]loxymoron" on July 1, 2010. http://www.flickr.com/photos/f-oxymoron/4752989199/

6 - RWIS unit (from original Bulletin images).

7 - WSDOT Opening Chinook Pass. Taken from the Pacific Northwest Snowfighters website: http://www.wsdot.wa.gov/partners/pns/

8 - Flickr Creative Commons: Attribution and Non-Commercial Use search. Goldensecret14, uploaded by JillHannah on July 14, 2010. http://www.flickr.com/photos/jillhannah/4795106174/

9 - Deicing in Oregon using a distributor bar. Taken from the Pacific Northwest Snowfighters website: http://www.wsdot.wa.gov/partners/pns/photos.htm

10 and 11 - Taken from the Federal Highway Administration page titled: "Manual of Practice for an Effective Anti-icing Program: A Guide for Highway Winter Maintenance Personnel" at http://www.fhwa.dot.gov/reports/mopeap/mop0296a.htm

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13 and 14 - Taken from the Federal Highway Administration page titled: "Manual of Practice for an Effective Anti-icing Program: A Guide for Highway Winter Maintenance Personnel" at http://www.fhwa.dot.gov/reports/mopeap/mop0296a.htm

15 - Flickr Creative Commons: Attribution only search. No Snow Removal Beyond This Point, uploaded by "taberandrew" on May 30, 2007. http://www.flickr.com/photos/andrewbain/522363815/

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Source Water Protection Practices Bulletin

Managing Highway Deicing to Prevent Contamination of Drinking Water

United States Environmental Protection Agency

FACTS:

More than $2 billion is spent each year on winter road maintenance.

15 million tons of deicing salt are used each year.

Abrasives such as sand are often used in conjunction with deicing chemicals to provide traction.

Chloride is not naturally removed from water as it travels through soil and sediments.

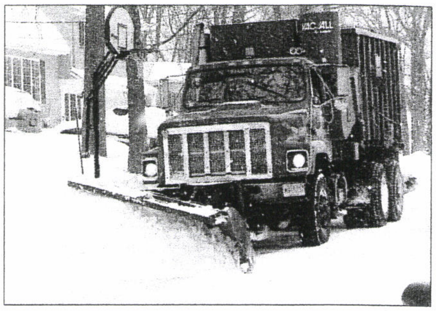
Individual measures might or might not be adequate to prevent contamination by themselves.

Better forecasting can prevent excessive application of anti-icing/deicing chemicals.

Alternative deicing chemicals may also be used for anti-icing.

***We depend on clear roads and highways for** safe travel and the uninterrupted flow of goods and services. Deicing chemicals help clear roads covered by snow and ice during the winter, but road runoff may later carry these chemicals to surface water and ground water sources of drinking water. This bulletin focuses on the management of highway deicing chemicals. See the bulletin on stormwater runoff for additional source water management measures.*

This document is intended to serve as a resource for professionals and citizens involved in planning, decision-making, and providing technical assistance in the areas of stormwater management and source water protection. Those who may find this bulletin useful include: state and regional source water, stormwater, nonpoint source control, Underground Injection Control (UIC), and other managers; water system operators; members or representatives of watershed groups; local officials and permitting authorities; developers; and federal and state highway agencies.



1– Big Red Snow Plow, NJ 2003

We depend on clear roads for safe travel and the uninterrupted flow of goods.

Inside this Bulletin:

USE OF HIGHWAY DEICING CHEMICALS

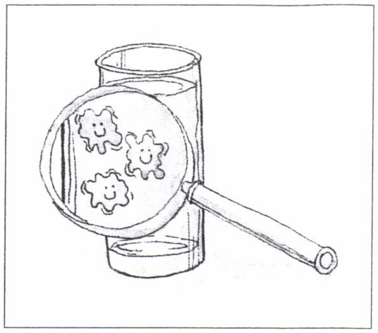
Each winter, state, county, and local transportation departments and private land owners prepare themselves for whatever winter storms may bring. Their tools include a variety of chemicals to melt snow and ice. This preparedness has a high price tag; in 2005, the Federal Highway Administration estimated that more than $2 billion is spent in the U.S. each year on chemicals, materials, labor, and equipment for winter road maintenance[1].

The most commonly used and economical deicer is sodium chloride, better known as salt; 15 million tons of deicing salt are used in the U.S. each year. Salt is effective because it lowers the freezing point of water, preventing ice and snow from bonding to the pavement and allowing easy removal by plows. However, the use of salt causes a number of environmental problems. Salt contributes to the corrosion of vehicles and infrastructure and can damage water bodies, ground water, and roadside vegetation.

These issues have led to the investigation and use of other chemicals as substitutes for and supplements to salt. Alternative deicing chemicals include magnesium chloride, potassium acetate, calcium chloride, calcium magnesium acetate (CMA), potassium chloride, and beet juice derivative. Abrasives such as sand are often used in conjunction with deicing chemicals to provide traction for vehicles, particularly on corners, at intersections, and on steep grades. When sand is overused, however, it often ends up in the environment, either as dust particles that contribute to air pollution or in runoff to streams and rivers.

WHY IS IT IMPORTANT TO MANAGE HIGHWAY DEICING NEAR SOURCES OF DRINKING WATER?

Surface water and ground water quality problems resulting from road salt use are causing concern among federal, state, and local governments. Salt contributes to increased chloride levels in ground water through infiltration of runoff from roadways[2]. Also, if runoff containing road salt reaches a stormwater injection well, it can provide a concentrated input of chloride to ground water. In some areas of the country, such as Woodbury, Connecticut, a type of injection well called a dry well drains stormwater runoff from parking lots and pavement directly into aquifer systems[3]. Unlike other contaminants, such as heavy metals or hydrocarbons, chloride is not naturally removed from water as it travels through soil and sediments and moves towards the water table. Once in the ground water, it may remain for a long time if ground water velocity is slow and it is not flushed away. Chloride may also be discharged from ground water into surface water and can account for elevated levels of chloride throughout the year, not just in winter[4]. Direct input of salt into surface water from runoff is also problematic[4,5]. Increasing chloride concentrations have been observed over the last few decades in streams, lakes, and ponds in northern climates that receive significant snowfall[6]. Reservoirs and other drinking water supplies near treated highways and salt storage sites are especially susceptible to contamination. Thus, regardless of the path that the runoff takes, salt poses a water quality problem. The best chance for long term mitigation is to reduce the application of salt to road surfaces in a manner that does not jeopardize public safety on the roads.



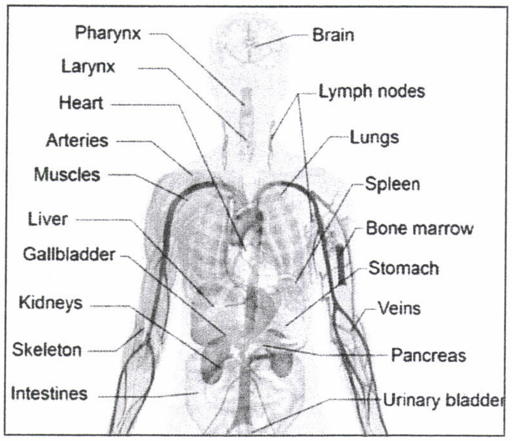
2 - Keep drinking water safe

{ Sodium can contribute to cardiovascular, kidney and liver diseases. }

HEALTH AND ENVIRONMENTAL CONCERNS

Sodium is associated with general human health concerns. According to the Centers for Disease Control and other health agencies[7,8], it can contribute to or cause cardiovascular, kidney, and liver diseases, and is directly linked to high blood pressure. Elevated sodium levels in sources of drinking water could prove harmful. There is no maximum contaminant level (MCL) or health advisory level for sodium; however, there is a Drinking Water Equivalent Level of 20 mg/L (a non-enforceable guidance level considered protective against non-carcinogenic adverse health effects).

Chloride, for which EPA has established a national secondary drinking water standard of 250 mg/L, adds a salty taste to water and corrodes pipes. It can also cause problems with coagulation processes in water treatment plants. The water quality standard for chloride is 230 mg/L, based on toxicity to aquatic life.



3- Anatomy showing heart, kidneys and liver (above)

4- Deicing an Airplane (below)

SALT FACTS:

Sodium chloride is better known as salt.

It lowers the freezing point of water, preventing ice and snow from bonding to the pavement.

It most effective at temperatures above 20° F.

Salt can corrode vehicles and infrastructure.

Runoff from deicing projects can contribute to increased chloride levels in ground and surface water.

There is no MCL for sodium but there is a Drinking Water Equivalent Level of 20 mg/L.

Chloride has a secondary drinking water standard of 250 mg/L and a Water Quality Standard of 230 mg/L.

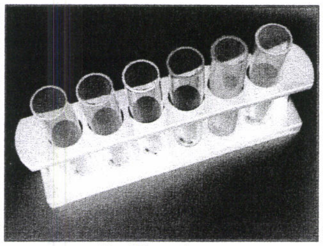
Salt is usually the cheapest of the deicing chemicals available.

It should be stored in a dry space away from wind to prevent movement.

This section provides an overview of several deicing management measures. The reference materials cited at the end of this document provide additional information. Please keep in mind that individual prevention measures might or might not be adequate to prevent contamination of source waters. Individual measures will likely need to be combined in an overall prevention approach that considers the nature of the potential source of contamination, the purpose, cost, and operational and maintenance requirements of the measures, the vulnerability of the source water, the public's acceptance of the measures, and the community's desired degree of risk reduction.

ALTERNATIVE DEICING CHEMICALS

Alternative deicing chemicals include calcium chloride, magnesium chloride, CMA , and products that are mixtures of chlorides and organic compounds[9]. Although such alternatives are usually more expensive than salt, their use may be warranted in some circumstances, such as near habitats of endangered or threatened species or in areas where the source water already has elevated levels of sodium or chloride. Sensitive areas and ecosystems along highways should be mapped, and the use of deicing alternatives should be targeted to those spots. Other considerations for using alternatives to salt include traffic volume and weather conditions.


5 - Chemistry

The various deicers are effective at different temperatures and have different environmental effects. For example, salt is most effective at temperatures above 20° F. As an alternative, calcium chloride is effective for temperatures that dip below 0°F and is fast acting, making it very useful in some parts of the country. It is, however, more expensive than sodium chloride. In New England, calcium chloride is often used on roadways in areas with high sodium concentrations in source water. It is less harmful to vegetation than sodium chloride, but it is corrosive to concrete and metal. Magnesium chloride is effective in extremely cold temperatures (as low as -13 °F). Magnesium chloride is also safer for vegetation, but can increase flaking of concrete. Calcium magnesium acetate (CMA) has the benefit of low toxicity to plants and microbes, but it is costly and is only effective above 23 °F. CMA can potentially lower dissolved oxygen concentrations in soils and receiving waters, damaging vegetation and aquatic life. Many communities, however, have used CMA with no apparent adverse environmental effects. Combining deicers, such as mixing calcium chloride and salt, can be cost-effective and safe if good information on weather conditions and road usage are available.

Innovative products have allowed some communities to reduce their salt usage. For example, a commercially available beet juice derivative or another product made from the leftover mash of alcohol distilleries can be applied to road surfaces, mixed with a brine for spray application, or used to treat salt. Salt treated with these compounds is effective at much lower temperatures than untreated sodium chloride, and it works quickly. The beet juice derivative, in particular, has been gaining popularity in the Midwestern United States. Communities such as Elkhart and Cloverdale, Indiana, for example, are finding that the beet juice helps salt and sand adhere to roadways, greatly reducing the amount of salt that needs to be applied. These products are biodegradable and are safer for roadside vegetation than sodium chloride. Communities are still gaining experience with these "eco-friendly" alternatives; additional research and experience with these and other alternatives are needed.

DEICING CHEMICALS:

Calcium Chloride is: $CaCl_2$

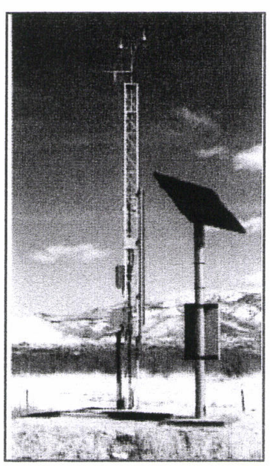
Magnesium Chloride is: $MgCl_2$

CMA (calcium magnesium acetate) is composed of:
Calcium carbonate: $CaCO_3$
Magnesium Carbonate: $MgCO_3$
Acetic Acid: CH_3COOH

Sodium Chloride is: $NaCl$

{Alternative deicing chemicals include calcium chloride, magnesium chloride, CMA, and products that are mixtures of chlorides and organic compounds}

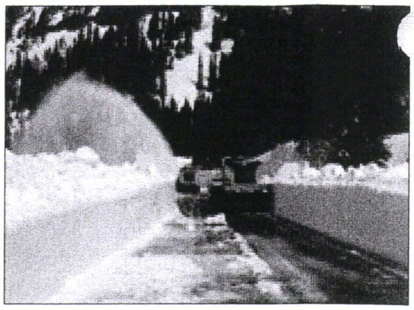
ROAD WEATHER INFORMATION SYSTEMS (RWIS)


6 - RWIS unit

RWIS help maintenance centers determine current weather conditions at a given location. They are a key component of winter maintenance programs in Japan and many Western European countries, and since the mid-1980s increasing numbers of states have been using this technology. Sensors collect data on air and pavement temperatures, levels of precipitation, and the amount of deicing chemicals on the pavement. The data are paired with weather forecast information to predict pavement temperatures for a specific area and to determine the amount of chemicals needed in the changing conditions. Savings from reduced use of deicers can offset the high cost of a RWIS. According to the Federal Highway Administration, the Massachusetts Highway Authority (MHA) saved $39,000 on salt and sand costs in the first year after installing nine RWIS stations. The MHA has estimated that a complete RWIS in Boston could save up to $250,000 per year[10]. A RWIS on a bridge over the James River in Virginia recovered 96 percent of equipment and installation costs over a single mild winter by avoiding unnecessary deicer application[11]. Information gathered through RWIS is also used to target anti-icing treatment (described below). Several states are developing satellite delivery of RWIS information to maintenance workers.

MAINTENANCE DECISION SUPPORT SYSTEMS (MDSS)

MDSS utilize state-of-the-art weather forecasting and data fusion techniques and merge them with computerized winter road maintenance rules of practice. The result is better forecasting of surface conditions along with customized treatment recommendations for winter maintenance managers. These measures help minimize the potential for excessive application of anti-icing/deicing chemicals and can result in significant reductions in their use[12].



7 - WSDOT opening Chinook Pass

ANTI-ICING OR PRETREATMENT

Anti-icing or pretreatment methods involve the application of deicing chemicals to roads prior to a storm to prevent ice and snow from bonding to paved surfaces, making roads easier to clear. Several states have reported improvements in traffic mobility and traction after using anti-icing techniques. Anti-icing can reduce the amount of deicing chemicals needed; a collection of estimates from state departments of transportation compiled by the Dupage River Salt Creek Workgroup showed reductions in deicer usage varying from 41 to 75 percent[13].

Alternative deicing chemicals, such as magnesium chloride, a sodium chloride brine, CMA, or the newer "eco-friendly" deicers (e.g., beet juice derivative and distillery byproducts) may also be used for anti-icing. Timing is important in this process, and weather reports or RWIS data can assist highway departments in determining the best time and place to apply the anti-icing chemicals. The Southeast Michigan Council of Governments recommends application of anti-icers two hours before weather events for maximum effectiveness[14].

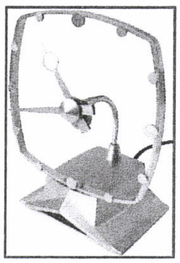
The Pacific Northwest Snowfighters (PNS) Association evaluates the safety, environmental preservation, and performance of winter road maintenance products, including road deicers and anti-icers. PNS maintains, monitors, and updates a list of approved products on its Web site[15].

Some states have installed fixed chemical spraying systems in highway trouble spots, such as on curves and bridges, to prevent slippery roads. Chemicals are dispensed through spray nozzles embedded in the pavement, curbs, barriers, or bridge decks. Using pavement temperature and precipitation sensors, maintenance workers can monitor conditions and activate these fixed maintenance systems. This technique saves materials and labor expenses and reduces the use of deicing chemicals during a storm. These systems are especially useful in locations such as bridges that cross sensitive water bodies because the system's high efficiency reduces the risk of over-application. Additional advice on anti-icing is provided in a 2004 article by Brown in Road and Bridges Magazine[16] and in guidance by the Federal Highway Administration[17].

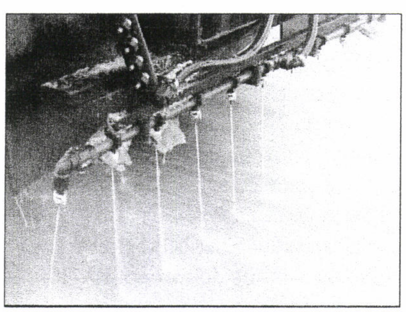
{Apply anti-icing chemicals 2 hours before weather events for maximum effectiveness.}

AMOUNT AND RATE OF SPREADING

Spreading rates and the amount of deicer used are important considerations. Snow tends to melt faster when salt is applied in narrow strips. In a technique known as windrowing, spreading is concentrated in a four to eight foot wide strip along the centerline to melt snow to expose the pavement, which in turn warms a greater portion of the road surface and causes more melting. This technique can be used on lesser traveled roads. The amount used is important; too much deicer is wasteful because the excess chemicals will just be dispersed (to the side of the road). If not enough deicer is used, the chemical interaction with ice needed for melting will not occur, wasting the application. Here is where knowledge of the road location and weather conditions is needed. For example, shaded areas have lower pavement temperatures and ice forms more easily. Therefore, heavier applications may be needed in these spots. As a general rule, less chemical should be used when the temperature is rising, and more should be used when it is falling.



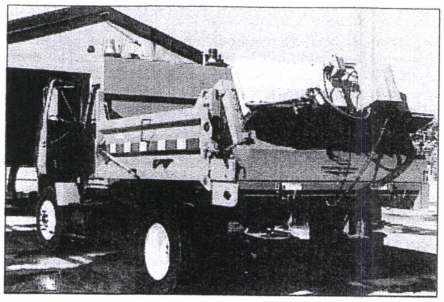
8 - Timing



9 - Oregon, deicing using a distributor bar

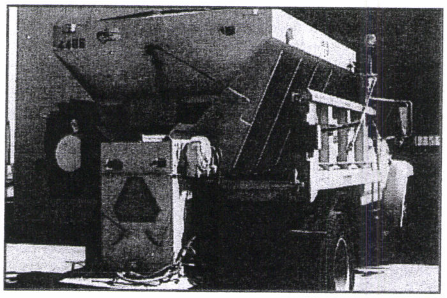
TIMING OF APPLICATION

Timing of application is an important consideration; it takes time for salt and other deicers to become effective, after which a plow can more easily remove the snow. Sand should not be applied to roadways if more snow or ice is expected soon, as it will no longer be effective once covered. Traffic volume should also be taken into consideration, as vehicles can disperse deicers and sand to the side of the road. The timing of a second application should be dictated by the road conditions. For example, while the snow is slushy on the pavement, the salt or deicer is still effective. Once it stiffens, however, it is best to plow first to remove excess snow.



10 - Under-tailgate spreader with prewetting equipment (above)

11 - Hopper type spreader (below)



APPLICATION EQUIPMENT

Appropriate application equipment aids in the proper distribution of deicing chemicals. Many trucks are equipped with a spinning circular plate (i.e., "spinner") that throws the chemicals in a semi-circle onto the road. However, this method of application can lead to significant salt wastage because the salt has enough momentum to bounce or roll away from the application area. A study by the Indiana Department of Transportation[18] found that salt applied by ordinary spreaders ends up off pavement 30 percent of the time and in non-target areas on the pavement 24 percent of the time. To correct for this problem, zero-velocity spreaders have been developed that "place" salt on the road with little impact velocity, reducing waste. For windrows, a chute is used to distribute chemicals, typically near the centerline of the road.

Spreader calibration controls the amounts of chemicals applied and allows different chemicals to be distributed at different rates. Modified spreaders prevent the over-application of materials by calibrating the application rate to the speed of the truck. Automatic spreader/controller systems are also available that continuously adjust for the speed of the truck and speed of the auger. A study led by the Wisconsin Department of Transportation has indicated that such systems can reduce unnecessary salt application by as much as 47 percent[19].

Equipment can also be used to vary the width of the deiced area. General equipment inspection and maintenance should be conducted at least once a year to ensure proper and accurate operation. Follow-up inspections during the snow removal season can also help detect problems caused by in-season equipment wear and tear.

{ Salt applied by ordinary spreaders ends up off pavement 30% of the time and in non-target areas 24% of the time. }

EMPLOYEE TRAINING AND EDUCATION

Employee training and education is as important as proper, well maintained equipment. This is especially true in light of rapidly evolving best management practices and the increasing complexity and variety of snow management options. Training can help counteract pressures to overuse salt, especially when past job performance was measured by the quantity of salt applied per shift. Supplying operators with the tools and knowledge necessary to make better decisions on the road can lead to significant reductions in salt usage, as was observed in one Minnesota Department of Transportation Program[20] aimed at improving operator decision making and rewarding improved performance. Suggestions for training modules from the American Association of State Highway and Transportation Officials include discussing spreader calibration, electronic spreader settings, integrating RWIS data, and anti-icing fluids[20]. Training may entail providing road maintenance workers with access to information on road conditions through the use of technology. Generally, optimal strategies for keeping roads clear of ice and snow will depend on local climatic, site, and traffic conditions. Personnel should also be made aware of areas where careful management of deicing chemicals is particularly important (e.g., near sensitive water areas such as lakes, ponds, and rivers). Similarly, workers should be aware of runoff concerns from roadways that drain to either surface water or the subsurface (e.g., through a dry well or other infiltration structure). In some regions, "no salt" zones have been established near and on bridges and other sensitive areas.

DEICING AND ANTI-ICING:

A good forecast using RWISs and/or MDSSs, or plowing snow away, can save money and deicing chemicals.

MHA saved $39,000 on salt and sand in one year by installing RWISs.

By using anti-icing techniques, deicer usage can drop from 41-75%.

Alternative deicing chemicals may be used for anti-icing.

Fixed chemical spraying systems are useful in spots with continuous trouble every year.

Automatic spreaders can reduce unnecessary salt application by 47%.

Snow melts faster when salt is applied in narrow strips or as brine.

Windrows use a chute to apply deicers to a 4-8ft strip along the centerline of a road.

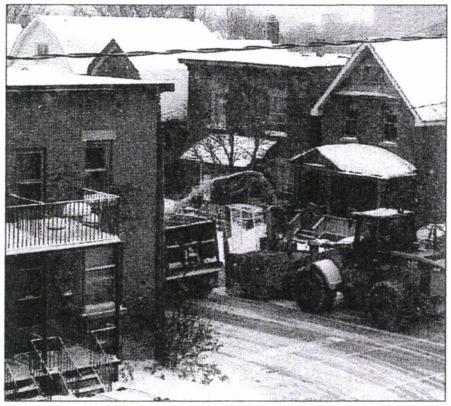
Deicers are effective if the snow is still slushy.

Job performance is no longer measured by how much salt is applied per shift.

{Sand can be filtered out of sweepings and added back to sand piles for future use. Any runoff brine should also be collected and reused.}

PLOWING AND SNOW REMOVAL

Plowing and snow removal are chemical-free options to keep roads clear of snow and ice. With plowing, less deicing material is needed to melt the remaining snow and ice pack. For specific weather conditions, specialized snow plows may be used. For example, various materials such as polymers and rubber can be used on the blade.



12 - Snow vacuum Canada

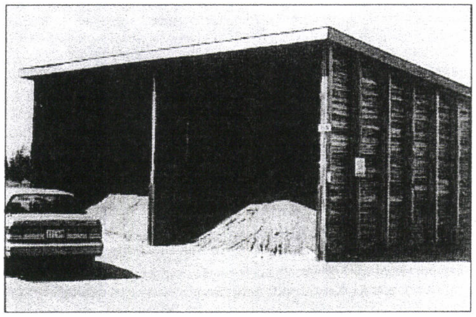
STREET SWEEPING

Street sweeping during or soon after the spring snow melt can prevent excess sand and deicing residue from entering surface and ground waters. Many road departments sweep and/or vacuum streets at least once in the spring. Sand can be filtered out of the sweepings and added back to the sand piles for future reuse.

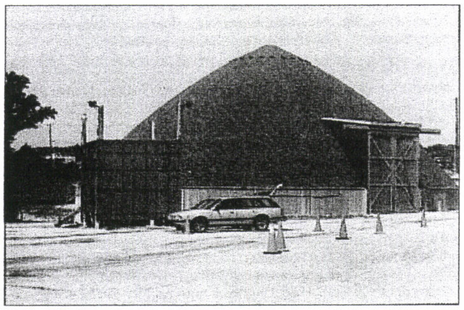
PRE-WETTING

Pre-wetting of sand or deicing chemicals is a widespread practice because salt needs moisture to become a melting agent. The resulting brine mixture can provide faster melting. Salt can be pre-wetted through a spray as it leaves the spreader. Sand is often pre-wetted with liquid deicing chemicals just prior to spreading; this is an effective method for embedding the sand into the ice and snow on the pavement. Pre-wetting can pay for itself through the savings in materials because less sand or salt is lost by bouncing off the pavement.

{Salt storage sites should be located outside of wellhead and source water protection areas.}



13 - Simple roof over stockpile



14 - Enclosed structure for chemical storage

GROUNDWATER QUALITY MONITORING

Ground water quality monitoring near salt storage and application sites should be performed at least once each year. Site-specific water table maps that show the direction of ground water flow should be reviewed, and monitoring performed up-gradient and down-gradient of storage and selected application sites to detect contamination.

PROPER SALT STORAGE

Proper salt storage is key to preventing the introduction of potentially harmful contaminant loads to nearby surface and ground waters. Salt storage sites should be located outside of wellhead and source water protection areas, away from private wells, sole source aquifers (where feasible), and public water supply intakes. These areas should be identified so that application can be controlled and storage precautions implemented. It is important to shelter salt piles from moisture and wind because unprotected piles can contribute large doses of salt to runoff. Salt should be stored inside a covered, waterproof structure such as a dome or shed. A liner or impermeable concrete slab may also be appropriate. Any runoff should be cleaned up immediately and the collected brine reused. Spills during loading and unloading should be cleaned as soon as possible.

These resources contain information on deicing chemicals, best management practices (BMPs), and related topics. Most of the documents listed are available without a fee on the Internet. State departments of transportation, whose contact information can be found on the Internet or in the phone book, are also good sources of information.

ORGANIZATIONS

Center for Watershed Protection, 8390 Main Street, Second Floor, Ellicott City, MD, 21043. http://www.cwp.org.
CWP also maintains the Stormwater Manager's Resource Center, http://www.stormwatercenter.net.

The Salt Institute, 700 N. Fairfax Street, Suite 600, Alexandria, VA 22314. Website contains information on salt storage and its Sensible Salting Program. http://www.saltinstitute.org.

USEPA links to sites on roads, highways, and bridges: http://www.epa.gov/owow/nps/roadshwys.html.

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Effects of Highway Deicing Chemicals on Shallow Unconsolidated Aquifers in Ohio —Final Report

By Allison E. Kunze and Bernard N. Sroka

U.S. Geological Survey Scientific Investigations Report 2004-5150

Prepared in cooperation with the
Ohio Department of Transportation and the
U.S. Department of Transportation, Federal Highway Administration

This report is available as a pdf.

Abstract

As a result of concerns about salt intrusion into drinking water aquifers, the effects of highway deicing chemicals on shallow aquifers were studied at eight locations in Ohio from 1988 through 2002. The study was done by the U.S. Geological Survey, in cooperation with the Ohio Department of Transportation and the Federal Highway Administration. Sites were selected along major undivided highways where drainage is by open ditches and ground-water flow is approximately perpendicular to the highway. Records of deicer application rates were kept, and apparent movement of deicing chemicals through shallow, unconsolidated aquifers was monitored by means of periodic measurements of specific conductance and concentrations of dissolved sodium, calcium, and chloride. The State routes monitored were the following: State Route (SR) 3 in Ashland County, SR 84 in Ashtabula County, SR 29 in Champaign County, SR 4 in Clark County, SR 2 in Lucas County, SR 104 in Pickaway County, SR 14 in Portage County, and SR 97 in Richland County.

The study began in 1988 with background data collection, extensive literature review, and site selection. This process, including drilling of wells at numerous test sites and the eight selected sites, lasted 3 years. Routine groundwater sampling at 4- to 6-week intervals began in January 1991 and

continued through September 1999. A multilevel, passive flow ground-water sampling device was constructed and used. Other conditions monitored on a regular basis included ground-water level (monitored continuously), specific conductance, air and soil temperature, precipitation,chloride concentration in soil samples, and deicing-chemical application times and rates.

Evidence from water analysis, specific-conductance measurements, and surface-geophysical measurements indicates that three of the eight sites (Ashtabula County, Lucas County, and Portage County sites) were affected by direct application of deicing chemicals. Climatic data collected during the study show that cold weather, and therefore deicing-chemical application rates, varied from south to north across the State. As a consequence, only minor traces of dissolved chloride (mean, 24–43 mg/L (milligrams per liter)) above background concentrations (mean, 13–23 mg/L) were determined in ground-water samples from the southernmost sites (approximately 3930' to 40 N latitude—Champaign County, Clark County, and Pickaway County). At the Ashland and Richland County sites (approximately 4030' N latitude), dissolved-chloride concentrations increased above background concentrations only intermittently (mean background concentrations 4–41 mg/L, rising to a mean of 40–56 mg/L in downgradient wells). At the northernmost sites (41 30' to 42 N latitude—Lucas County, Portage County, and Ashtabula County), deicing-chemical application was consistent throughout the winter, and downgradient dissolved-chloride concentrations (mean, 124–345 mg/L) rarely returned to background concentrations (mean, 7–37 mg/L) throughout the study period.

Other factors than application rate that may affect the movement of deicing chemicals through an aquifer were precipitation amounts, the types of subsurface materials, ground-water velocity and gradient, hydraulic conductivity, soil type, land use, and Ohio Department of Transportation deicing priority.

CONTENTS

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